Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 55 (1987)

Artikel: Sulphur concrete for foundations in the Arabian Gulf Area

Autor: Al-Tayyib, Abdul-Hamid J. / Al-Mana, Abdulaziz I. / Khan, Mohammed S.

DOI: https://doi.org/10.5169/seals-42748

Sulphur Concrete for Foundations in the Arabian Gulf Area

Béton de soufre pour les fondations dans les régions du Golfe Arabique

Schwefel-Beton für Fundamente im Arabischen Golf

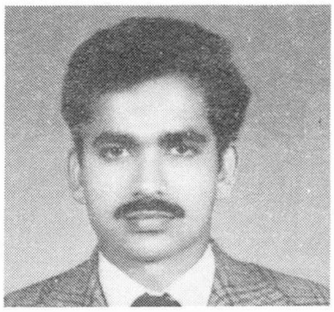
Abdul-Hamid J. AL-TAYYIB
Manager
Research Inst., KFUPM
Dhahran, Saudi Arabia

Abdul-Hamid J. Al-Tayyib, born in 1946, obtained his Ph. D. in Civil Engineering from Texas Tech. University, Lubbock. At present, he is Manager of the Materials and Building Technology Program of the Research Institute at KFUPM.

Abdulaziz I. AL-MANA
Manager
Research Inst., KFUPM
Dhahran, Saudi Arabia

Abdulaziz I. Al-Mana, born in 1941, obtained his PH. D. in Civil Engineering from Stanford University. At present, he is Manager of the Metrology, Standards and Materials Division of the Research Institute at KFUPM.

Mohammad S. KHAN
Engineer-II
Research Inst., KFUPM
Dhahran, Saudi Arabia



Mohammad S. Khan, born in 1957, obtained his M.S. degree in Civil Engineering from King Fahd University of Petroleum and Minerals (KFUPM). At present, he is working in the Research Institute of KFUPM.

SUMMARY
In this paper, the possibility of using sulphur concrete in foundations has been examined. The early gain in strength, high strength, low permeability and high electrical resistivity of sulphur concrete are all in favor of its use as a foundation material. However, the bond characteristics and the in-situ performance of sulphur concrete, particularly in terms of its reinforcement corrosion, are some of the parameters that need to be further investigated, before the material can be used in foundations with confidence.

RÉSUMÉ
Il existe une possibilité d'utiliser du béton de soufre dans les fondations. L'augmentation rapide de la résistance mécanique, la faible perméabilité et la haute résistivité électrique de ce béton sont favorables à une utilisation comme matériau de fondation. Cependant, les caractéristiques d'adhérence et le comportement "in-situ" du béton de soufre, la corrosion de l'armature sont quelques-uns des paramètres qui nécessitent une étude plus approfondie en vue d'une utilisation sûre de ce matériau dans les fondations.

ZUSAMMENFASSUNG
Es werden Untersuchungen über die Verwendung von Schwefel-Beton für Fundamente im Arabischen Golf beschrieben. Die hohe Festigkeit, die kleine Durchlässigkeit und der hohe elektrische Widerstand sprechen für die Verwendung von Schwefel-Beton in Fundamenten. Verbundprobleme und das Verhalten des Betons bezüglich der Bewehrungskorrosion zeigen jedoch, dass noch weitere Untersuchungen durchgeführt werden müssen, bevor dieser Betontyp praktisch verwendet werden kann.

INTRODUCTION

The foundations of one or two storey housing units in the Arabian Gulf area are usually constructed with steel reinforced Portland cement concrete (PCC) of typical mix designs that give a compressive strength of the order of 20 to 28 MPa (3000 to 4000 psi). Such PCC is relatively porous and when it is placed in grounds with high water table, as is the case all along the coastal areas of the Arabian Gulf, they act as tree-roots and transfer the salt laden ground water to the remaining structural members of the housing unit by capillary action. The concentration of salts increases in the concrete pores. This and other corrosion collaborating parameters lead to the corrosion of steel reinforcement in those concrete structural members in a short period of time.

In this paper, an experimental study has been carried out to examine the possibility of using sulphur concrete (SC) as an alternate to PCC for foundation constructions in the Arabian Gulf area. SC, is a relatively impermeable thermoplastic material which is composed of sulphur, coarse aggregate, sand, and filler powder. The present SC technology utilizes a modified (plasticized) sulphur cement which is prepared by reacting elemental sulphur with chemical modifiers, unlike the pure elemental sulphur used in early developments [1-4]. The modified sulphur cement reduces the brittleness of the resulting SC product, associated with elemental sulphur, and improves the durability of SC in aqueous environments. The SC produced by using modified sulphur cement, developed by U.S. Bureau of Mines researchers [1,2], has been successfully used in a major rehabilitation project in which 2700 m^2 (29000 ft^2) of a deteriorated PCC floor was overlaid with 9 cm (3.5 in) thick unreinforced SC, and 530 m^2 (5700 ft^2) of walls and piers were lined or encapsulated with 10 cm (4 in) thick unreinforced SC [5]. The U.S. Bureau of Mines modified sulphur cement is produced by reacting elemental sulphur and chemical modifier in a ratio of 19:1 at 145^{o}C (293^{o}F) for 6 hours. The chemical modifier consists of dicyclopentadiene (DCPD) and oligomers of cyclopentadiene (CPD) in equal proportions. The other examples of commercial application of SC are the repair of PCC foundations and highways [6,7].

The production technique of SC involves the blending and heating of coarse aggregate, sand and filler powder to a temperature of 171 to 193^{o}C (340 to 380^{o}F) and then mixing these constituents with modified sulphur cement. A hot homogeneous mixture in the temperature range of 127 to 149^{o}F (260 to 300^{o}F) is obtained which can easily be poured, vibrated and finished [8]. Various types of mixers such as heat jacketed concrete transit mixers and modified mobile asphalt batch plants are used in in-situ SC casting. The working time available for placing and finishing of SC is relatively short. It is approximately 30 minutes for large SC batches. Efforts are needed to minimize the heat loss from the SC mixture during the entire casting operation. Concrete buggies with insulated hoppers should be used to transport the hot SC mixture from the mixer to the placement area. Some heat source such as an infrared heating unit should be used to reheat SC if it starts solidifying before finishing. The SC cures within 6 hours and attains about 80% of its final strength. Unlike PCC, the casting of SC requires more safety measures. This includes the use of protective clothing, safety glasses, face shields, gloves and hard hats by the personnel involved in SC casting. The emission of toxic gases such as sulphur dioxide and hydrogen sulphide can be controlled well below the allowable threshold limit, if the temperature of hot SC mixture is maintained in the range of 127 to 149^{o}C (260 to 300^{o}F).

The compressive strength of SC ranges between 35 MPa to 62 MPa (5000 to 9000 psi) depending upon the sulphur cement content and the type and grading of the aggregate. The tensile and flexural strengths of SC are 12 to 15% and 15 to 20% of its compressive strength respectively. Its modulus of elasticity is of the order of 27.5 GPa (4 x 10^6 psi) [2]. SC is classified as a concrete with high resistance of chemical environments, unlike PCC which is easily attacked by various chemicals, particularly acids. The long term metallurgical and fertilizer processing plants has been evaluated in a joint research program by U.S. Bureau of Mines and The Sulphur Institute [2]. After 3 to 5 years of exposure, the performance of SC in most of the acidic environments has been reported satisfactory. In similar environments, PCC has been partially or completely destroyed.

A cost analysis by Muir [9] for the year 1985 indicates that on cost basis SC is competitive with PCC. The cost of 35 to 55 MPa (5000 to 8000 psi) PCC ranges from 45 to 68 dollars per cubic meter. The same strength SC can be produced at a cost of 39 to 46 dollars per cubic meter.

EXPERIMENTAL STUDY

In this study, some properties of SC considered significant in its evaluation as a foundation material such as water absorption, electrical resistivity, resistance to reinforcement corrosion and bonding with PCC, were determined. These properties were then compared with those of PCC. The SC was produced by using the modified sulphur cement, Chement 2000 developed by U.S. Bureau of Mines [1,2]. The locally available coarse aggregate, dune sand and limestone filler powder (minus 75 micron sieve) were used in the SC production. The laboratory casting procedure followed was similar to that described in the preceding section.

For water absorption, electrical resistivity and reinforcing steel corrosion tests, 75 mm ϕ x 150 mm (3 in ϕ x 6 in) cylindrical specimens were prepared from different SC and PCC mixes. For the reinforcing steel corrosion tests, the cylindrical specimens were provided with a 13 mm diameter (#4) steel bar placed in the center with a clear cover of 32 mm (1.25 in). Three mix designs for SC, 15/10/75 (SC-1), 18/10/72 (SC-2) and 22/10/68 (SC-3) by weight of sulphur cement, filler powder and total aggregate were used. The coarse aggregate and sand were used in equal proportions. The PCC mixes were designed with different water-cement (w/c) ratios of 0.4 (PCC-1), 0.55 (PCC-2) and 0.7 (PCC-3). A cement content of 450 kg/m^3 (758 lb/yd^3) was used with coarse aggregate and sand in equal proportions.

The water absorption was measured by calculating the percentage increase in the weight of dry SC specimens after 24 hours of immersion in water at 21^oC (70^oF). In case of PCC, the specimens were oven-dried at 110^oC (230^oF) for 24 hours and then allowed to cool before immersion in water. The electrical resistivity measurements were made by using a commercially available resistivity meter, Nilsson 400. The impressed voltage, half-cell potential, and corrosion rate measurement techniques used in this study for corrosion testing have been described elsewhere [10].

To study the bond behavior of SC with PCC, composite cylinders, 150 mm ϕ x 300 mm (6 in ϕ x 12 in) were prepared with one half consisting of SC and the other half PCC having a diagonal bond line joining the two halves of the cylinder at a plane of 30^o from the longitudinal axis (see Fig. 1). When casting, the test of SC (or PCC) portion of the composite cylinder was allowed to cure properly before casting the other portion of the cylinder. In one set of specimens, SC was cast first followed by casting PCC while in another set of specimens PCC eas cast first then SC. In these tests, SC with mix proportions of 25/10/36.5/28.5 by weight of sulphur, silica flour filler, limestone aggregate, and dune sand; and PCC with w/c ratio of 0.4 were used. The compressive strength of the composite cylinder was compared with similar complete cylinder made of SC and PCC.

The composite cylinder test developed by Arizona Highway Department is used to test the bond between epoxy compounds and PCC in repair works. In these tests, if the composite cylinder consisting of two halves of PCC and an epoxy compound, has 90% of the compressive strength of the homogeneous PCC cylinder, then the bond of the epoxy compound with PCC is considered satisfactory.

All the tests were carried out on a set of at least 3 specimens.

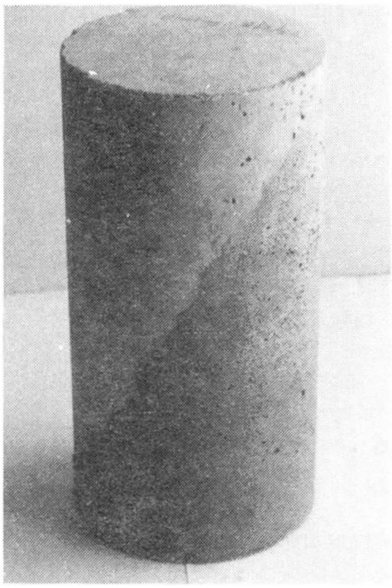


Fig. 1 Composite Cylinder of SC and PCC used for bond test

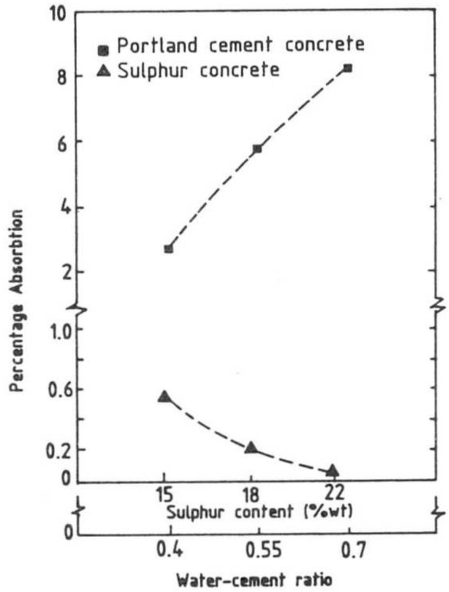


Fig. 2 Absorption of SC and PCC

RESULTS AND DISCUSSION

Water Absorption

The water absorption of the different SC and PCC mixes is shown in Fig. 2. It is noticed that the water absorption of the SC mixes varies from 0.04 to 0.55% as compared to 2.75 to 8.23% in case of the PCC mixes. The low permeability of SC is one of the main factors responsible for its high resistance against various corrosive solutions. The recommended water absorption of a corrosion resistant SC is less than 0.1% and preferably below 0.05% [8]. In this study, the acceptable water absorption is obtained in a SC mix containing 22% sulphur cement (see Fig. 2). This amount is in excess of optimum sulphur cement requirement from the point of view of strength and it causes undesirable shrinkage of finished SC. A sulphur cement content of 18% which has been found optimum in this study as far as strength and workability are concerned, has yielded SC with water absorption of 0.2%. On the other hand, Sullivan [8] has produced SC with less than 0.05% water absorption by using 16% sulphur cement. The higher water absorption of SC, even with increased sulphur cement content, obtained in this study is attributed to the quality of the coarse aggregate. As the limestone coarse aggregate used does not meet the criteria of an acceptable aggregate used in SC production. The water absorption of the aggregate used is 2.2% as compared to a maximum recommended value of 1% [2]. It is worth mentioning that a compressive strength of 57 MPa (8265 psi) has been obtained in this study for the optimum mix SC-2.

Electrical Resistivity

The SC and PCC specimens subjected to electrical resistivity measurements have been partially immersed in 5% sodium chloride solution for 15 months. The electrical resistivity of all the SC mixes, SC-1, SC-2 and SC-3 have been found in excess of 4.9×10^6 ohm-cm respectively. The electrical resistivity of SC could not be measured beyond 4.9 x 10^6 ohm-cm because the instrument used has a maximum range of 1.1 mega ohms which corresponds to an electrical resistivity value of 4.9 x 10^6 ohm-cm for the size of specimens used in this study.

The high electrical resistivity of SC is due to the fact that SC, unlike PCC, does not include water in its composition and also its low permeability reduces the ingress of environmental moisture. The hydrated cement paste of PCC provides an easy path for charge transfer. The significance of electrical resistivity has been realized in the reinforcement corrosion of PCC. Stratfull [11], on the basis of his field investigation has pointed out that deterioration of PCC due to reinforcement corrosion is negligible when its electrical resistivity is in excess of 60,000 ohm-cm.

Corrosion of Reinforcing Steel

In the impressed voltage testing, SC and PCC specimens have been tested under a constant voltage of 6 volts versus saturated calomel electrode (SCE). The variation of current has been recorded with time. Usually, a sharp rise in current has been found coincident with the time of visible cracking of concrete. The reinforced specimens have been immersed in 5% sodium chloride solution for a period of 5 months before testing.

The obtained results indicate that the current flow in all the SC specimens is negligible. A maximum current of 2.7 mA has been recorded after 60 days of testing. None of the specimens from the SC mixes have shown any cracking after 60 days. On the other hand, in case of PCC specimens current values as high as 170 mA have been recorded and the time needed for the appearance of first crack has been found to be 60, 36 and 12 hours for mixes PCC-1, PCC-2 and PCC-3 respectively. Figure 3 compares the variation of current with time in typical SC and PCC specimens. On the basis of these results, one may conlcude that the resistance of SC against reinforcement corrosion is much higher than that of PCC. In this case, the better performance of SC is attributed to its low permeability and high electrical resistivity. As the low permeability reduces the ingress of corrosion inducing agents (oxygen, water and chlorides) to the steel surface and the high electrical resistivity reduces the current associated with electrocemical corrosion process.

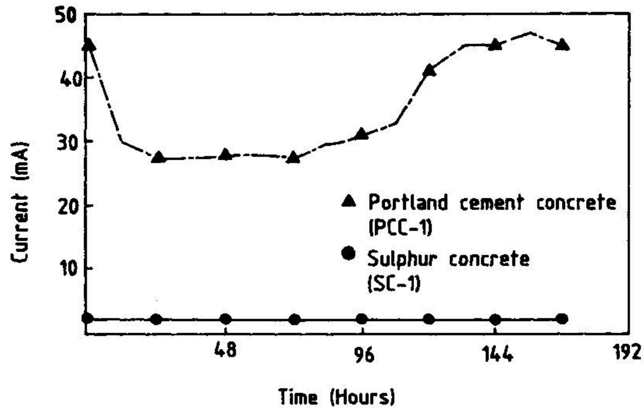


Fig. 3 Variation of current with time in SC and PCC specimens in impressed voltage testing

The corrosion monitoring results of another set of SC and PCC specimens partially immersed in 5% sodium chloride solution (without impressed voltage) for an extended period of 24 months are shown in Table 1. An important observation that can be made from these results is that the time to active potential of reinforcing steel in SC specimens is much longer than that in PCC specimens, but the corrosion rates are not as low as it was expected after the impressed voltage testing.

Mix Designation	Time to Active Potential (days)	Half-cell Potential (mV vs. SCE)	Corrosion Rate (μm/year) (Linear Polarization Resistance Technique)
Sulphur Concrete			
SC-1 (15/10/75)	126	-577	0.63
SC-2 (18/10/72)	++	-205	0.33
SC-3 (22/10/68)	77	-587	0.11
Portland Cement Concrete			
PCC-1 (w/c = 0.4)	84	-450	0.88
PCC-2 (w/c = 0.55)	77	-500	2.60
PCC-3 (w/c = 0.70)	36	-550	4.40

++ Passive Potential after 24 months of immersion in 5% sodium chloride solution.

Table 1 Corrosion monitoring results after 24 months immersion of SC and PCC specimens in 5% sodium chloride solution.

One of the factors that has probably contributed to lowering the reinforcement corrosion resistance of SC during the long term exposure in sodium chloride solution is the use of low quality coarse aggregate in this study. The access of corrosion inducing agents to the steel surface in SC is possible after long time immersion in aquous solution by the micro or macro cracks developed due to non-compatible volume changes of sulphur matrix and the moisture absorptive aggregates. These type of cracks may also be developed due to the presence of swelling minerals in the aggregate or filler powder. The presence of swelling mineral mica has been identified in the limestone filler powder used in this study [12]. Cracks of such nature have been found on some unreinforced SC specimens after 24 months of exposure time, although they were not detected at earlier stages. The unreinforced specimens from the same mixes were immersed together with reinforced specimens for detecting these type of cracks. It is expected that the use of good quality aggregates and filler powder would ensure a long term superior performance of SC against reinforcement corrosion.

Bonding Behavior of SC with PCC

The compressive strength of composite cylinders of SC and PCC along with those of SC and PCC cylinders is shown in Table 2. It can be observed that the compressive strength of composite cylinders is 27 to 45% of that of SC cylinders and 20 to 32% of that of PCC cylinders. The set of composite cylinders that had a rough bond surface made by a chisel have shown 13% higher strength than similar cylinders cast with smooth surface. The failure of most of the specimens is in the form of slip along the bond surface. Based on the bond criteria developed by Arizona Highway Department, the bonding between SC and PCC is not adequate.

Specimen Type	Average compressive strength [kg/cm² (psi)]
Composite; PCC top, SC bottom Smooth bond surface.	108 (1536)
Composite; SC top, PCC bottom Smooth bond surface.	154 (2190)
Composite; SC top, PCC bottom Rough bond surface.	177 (2517)
Complete SC.	397 (5645)
Complete PCC.	555 (7892)

Table 2 Compressive strength of SC and PCC composite cylinders having a diagonal bond line.

CONCLUDING REMAKRS

The results obtained in this study indicate that SC may be potentially used in foundation construction. However, there are certain problems that must be resolved before the use of this material in such a critical application can be ascertained. Most important is the selection of a good quality aggregate that would ensure production of good quality SC with extremely low moisture absorption and improved resistance against reinforcement corrosion in long term exposure. The selected aggregates, as apecified by some U.S. Bureau of Mines reports, must be clean, hard, tough, strong, durable and free from any swelling constituents. Further, field testing need to be conducted and monitored to assess long term performance of this material in in-situ environment. In this regard, it is suggested that reinforced SC specimens made with acceptable quality aggregates and filler powder be burried in grounds of high water table and tested at different periods to observe the changes in material properties that may take place. Another problem of concern in using SC as a foundation material is the poor bonding between SC and PCC. This problem might be resolved by investigating the use of some bonding agent such as a mixture of styrene butadiene rubber (SBR) latex and cement slurry used in PCC repairs.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the support of the Research Institute at King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia.

REFERENCES

1. MCBEE, W.C., SULLIVAN, T.A. and JONG, B.W., Modified Sulfur Cements for use in Concretes, Flexible Pavings, Coatings and Grouts. Research Report RI 8547, U.S. Bureau of Mines, 1981, 24 pp.

2. MCBEE, W.C., SULLIVAN, T.A. AND FIKE, H.L., Sulfur Construction Materials. Bulletin 678, U.S. Bureau of Mines, 1985, 31 pp.

3. VROOM, A.H., Sulfur Cements, Process for Making Same and Sulfur Concretes Made Therefrom. U.S. Pat. 4,058,500, November 15, 1977.

4. GILLOT, J.E., JORDAAN, I.J., LOOV, R.E. AND SHRIVE, N.G., Sulphur Concretes, Mortars and the Like, U.S. Pat. 4,188,230, February 12, 1980.

5. PICKARD, S.S., Sulphur Concrete at AMAX Nickel: Project Case History. Sulphur Research and Development, Vol. 7, 1983, pp. 19-24.

6. FOLEY, A.S., Repairing Foundations with Sulphur Concrete. Sulphur Research and Development, Vol. 9, 1985, pp. 4-5.

7. SULPHUR RESEARCH AND DEVELOPMENT, Sulphur Concrete used for Highway Repair. Sulphur Research and Development, Vol. 9, 1985, pp. 6-7.

8. SULLIVAN, T.A., Corrosion Resistant Sulfur Concretes - Design Manual. The Sulphur Institute, Washington, D.C., U.S.A., 1982, 18 pp.

9. MUIR, D.R., Sulphur Supply/Demand and its Relevance to New Sulphur Products: An Examination of their Economic Viability. Proceedings of International Conference on Sulphur in Construction, CANMET, Energy, Mines and Resources, Ottawa, Canada, 1978, pp. 1-16.

10. AL-TAYYIB, A.J. and KHAN, M.S., Testing Techniques for Reinforcement Corrosion in Portland Cement Concrete - A Review. Corrosion (submitted for publication).

11. STRATFULL, R.F., How Chlorides Affect Concrete Used with Reinforcing Steel, Material Protection, Vol. 7, No. 3, March 1968, pp. 29-34.

12. AL-TAYYIB, A.J., TEWFIK, M.F., BALUCH, M.H., AZAD, A.K. and KHAN, M.S., Effect of Filler Type on the Durability of Sulphur-Sand Composites in the Arabian Gulf Countries. The Arabian Journal for Science and Engineering, Vol. 11, No. 3, July 1986, pp. 225-234.